Systemic Risk: Simulating Local Shocks To A Global System

Scot A. C. Gould, Stephen A. Naftilan,
W. M. Keck Science Center
The Claremont Colleges
Claremont, California 91711-5916

Sarkis J. Khoury
The A. Gary Anderson Graduate School of Management
University of California, Riverside
Riverside, California 92521-0203

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Correspondence should be sent to: gould@physics.claremont.edu

Using our updated model of the payment exchange system within the banking industry, we have introduced sudden local economic shocks and calculated their effect on the stability of the financial system. Our results suggest that the probability of a total banking failure, i.e., the systemic risk of the system, is insignificant unless the degree of the shock and the degree of integration between banks are very large. We find that the larger the shock, i.e., the greater the amount of loss amongst all banks, and the more isolated banks are within the payment system, the greater the likelihood of a localized or global banking system failure. However, given the current limits percentages of capitol banks can loan each other, only worldwide economic crises of cataclysmic significance would cause a collapse of the entire banking system. Hence we affirm the findings of our previous work which considered the effects of a bank failure generated by factors internal to the banking system (internal instead of internal shocks), which suggest there is minimal systemic risk in an integrated, minimally regulated, banking system.

Introduction

Fears are often generated about the stability of the international financial system after any financial setback or disaster. This is usually reflected in the bond and stock markets. Either periodically, or in response to a financial crisis, financial institutions undergo extensive reviews of their risk management models. Government officials and other regulators frequently suggest ways, often in the form of new regulations, to "stabilize" the financial system in order to prevent systemic failure. Sometimes the financial crisis affects only a localized area such as a country like Russia or Mexico or a section of the world such as Asia or Latin America. Other times the crises can affect the entire globe. Still the dominant question is: Can financial systems fail, or is a liquidity crisis the worst of outcomes from a crisis caused by an external shock?

In this paper we continue our study of systemic risk (Gould, Naftilan, Khoury and Wright, 2000) and further refine the likelihood of systemic failure. Our research continues to show that systemic failure is practically impossible under the least restrictive assumptions of bank management behavior and the prudent man rule. The focus of this study is on the effects of sudden local economic shocks on the stability of the financial system.

As with our previous work, the number of variables involved in our model is too large to allow for a closed form solution for the estimation of the probability of a systemic failure. Indeed we have further complicate our simulation, but increased its accuracy, by adding the effects of local shocks on the financial system.

This paper is organized as follows: section 1 delivers the foundation to the model; section 2 describes our basic model from our previous work; section 3 describes the modifications to the model; section 4 presents the results of our simulations; and section 5 summarizes the results of the research.

Model Foundation

Systemic risk, the possibility that the sudden unanticipated failure of one or several banks could trigger a "domino-like" collapse of a large segment of the banking system, has been the subject of a number of publications. See: Agelietta (1996), Angelini, Maresca and Russo (1994), Bordo, Mizrach and Schwartz (1995), Giles (1996), Kaufman (1994) and Gould, Naftilan, Khoury & Wright (2000). By establishing a deposit insurance system, the federal government has established itself as a lender of last resort. However, it has also generated a large set of regulations aimed at minimizing the perceived possibility of a systemic failure. Concerns about systemic risk have grown recently as banks increasingly engaged in interbank loans, the foreign exchange markets, OTC derivative trading, and fast increasing volumes in the settlement systems.

There have been several studies on systemic risk which have focused on the interbank loan market and the settlement systems. On an average day, many trillions of dollars pass through the world's payment networks and settlement systems. It is known that daylight overdrafts are frequently huge, often exceeding the capital basis of the bank. In examining the possibility of systemic failure, the two largest payment systems, Fedwire and CHIPS, have received the most attention. Most researchers have focused on possible ripple effects in CHIPS, since the Federal Reserve guarantees payment finality in the Fedwire system that it administers. In his study, Humphrey (1986) took actual CHIPS balance sheets, and simulated the effect of one bank, usually the largest debtor on a given day, defaulting. His results suggested that unwinding linkage used by CHIPS could lead to a large number of linked failures. Due to these findings, CHIPS instituted new reserve requirements and regulations aimed at reducing these risks. The more recent study by McAndrews and Wasilyew (1995), henceforth referred to as MW, suggested even further possibilities of systemic failure.

The bank settlement system is not the only area of concern. It has been suggested that the foreign exchange market could be a source of systemic risk such as in the case of the Herstatt Bank failure in 1976. While derivatives are probably less of a concern, since the netting arrangements tend to keep the settlement payments small, and since members post large collateral and are limited in the amount of overdraft they can incur.

Given that most studies have suggested systemic risk is real and likely, Gould, Naftilan, Khoury & Wright (2000), henceforth referred to as GNKW, evaluated the risk by developing a simulation of the payment system. We began by examining the only working model for the payment system (MW) and found several unrealistic assumptions of their assumed payment system. From this analysis, we developed a more realistic and rigorous model. Using a simple rule, where banks would pool their payments, we showed that systemic risk was essentially impossible except in the most extreme cases. The prudent man rule, which we refer to as the diversification rule, was the minimal amount of regulation required to stabilize the entire financial system.

In this paper, we have refined our simulation outlined in the GNKW paper. We continue to be interested in three issues: 1) how does the number of banks in a system affect the possibility of systemic risk? 2) How does the likelihood of any two banks in the system exchanging loans (payments) affect the possibility of systemic risk? 3) How does the size of payments between banks affect the possibility of systemic risk? However to this we have added: 4) how does local financial crises affect the possibility of system risk? 5) How does globalization of the financial markets affect global systemic risk? 6) Is the prudent man rule still sufficient enough to limit the possibility of systemic failure?

In these questions we are addressing situations where sudden economic shocks affect a local area. These local shocks could come in the form of depressed real estate values localized to a city or state, or a sudden and very large devaluation of a currency to a country.

Description of the basic model:

For the basic model of the payment system, the banking industry consists of equal sized banks loaning money to each other. It is a closed system; hence, the sum of all debt within the system is equal to the net credit within the system. The general structure of the simulation consists of generating loans between banks, closing the bank with the largest net debt, handling the payments to and from the defaulting bank either by calling all loans from the defaulting bank or by paying off loans to other banks at a reduced rate, closing banks which suddenly experience an unexpected net loss and continuing until either no more banks remain or the remaining banks are able to absorb the total loss within the system. The closing of banks after the failure of the first bank is referred to as the unwinding of the system.

The condition used to determine if a bank must close, i.e, the unexpected net loss, was first used by David Humphrey (1986) who was also the first to simulate the effects of a failure in the payment system. In the model, banks that experience unexpected net losses beyond a pre-established threshold are forced to close. In the end, the model reports the key measurements of a successful payment settlement system: (1) the probability that the unwinding finds a non-zero subset of banks which can support the payments, and (2) the fraction of surviving banks after the default of the largest net debtor and the subsequent unwinding. We consider these measures acceptable indicators of the probability of systemic risk in the banking system.

As described in GNKW, the key parameters in the model are: N, the number of banks; p, the probability of any two banks exchanging payments (henceforth known as interaction probability); d, the threshold level of unexpected net debit (henceforth known as payment default threshold); and σ^2, the variance of the bilateral net debit between any two banks; r_L, the loan sale rate, i.e., the rate at which a bank receives payment on a loan to a defaulting bank. Typical values for N, the number of banks, are from 5 to 300; typical values used for the interaction probability, p are 0.1, 0.5 and 0.9; and typical values used for the loan sale rate, r_L, are 0.60 and 0.80. Since all banks possess an asset size of one, typical values of 0.02 and 0.03 are used for the payment default threshold, and values of 0.2 and 0.4 for the variance of bilateral net debit, depending upon the simulation.

Using the initial parameters described above, the simulation generates loans and closes banks when the unexpected net loss exceeds the payment default threshold. The unexpected net loss is

calculated by examining the difference between the original total bilateral net debit, referred to as the multilateral net debit at the beginning of the simulation and the multilateral net debit after the initial bank is closed. For more details, refer to the appendix at the end of the paper.
[Note: GNKW also investigated the effect that banks vary in asset size. For this study we kept all banks at an equal size.]

In our original study, we found likelihood of system risk was eliminated using a pooling technique known as the diversification rule. This rule attempts to distribute net debt from a single bank across the entire banking system. This rule is so successful that in our data, we could actually increase the variance of bilateral net debit an order of magnitude (from 0.04 to 0.4) thus allowing the banks to create even larger loans, or reduce the payment default threshold significantly thus making banks more sensitive to failure. In general, we found that by using the diversification rule, while the mean net loan value between any two banks decreases significantly, banks can still possess very large multilateral net debit - several times the size of their assets. In this paper we include the diversification rule with our modifications to the original model.

Description of Simulation modifications:

For this study, we made two basic modifications to the GNKW model (with or without the diversification rule). They were:

I) starting the simulation in a dynamic mode. Before, the banks were assigned, at random, payments with other banks after which the greatest net debtor was closed the unwinding process was initiated. In the new model, banks were allowed to exchange payments for several rounds and the closing of banks was not triggered until one of the following possible conditions occurred:

1) a bank within the system possessed a multilateral net debit beyond the payment default threshold;

2) the multilateral net debit was beyond several times the payment default threshold; or

3) a review of the banks was performed after some random number of rounds of payment exchanges.

We investigated the effects of the three possible conditions individually.

II) Add increased loss of income in local areas. To model the effects of local shocks, we created areas where there would be a local shock and hence we would find reduced values for loans in the payment system. For this we created a set of new parameters. The first was the p_L, the percentage of the banks that were within an area of sudden depressed currency or economic value, i.e., the percentage of banks within an area where a local shock occurs, and r_{sL}, the rate at which loans from these banks within the area would be repaid. Numerically, r_{sL} is less than r_L. Finally, we created a parameter d_L, the distance factor, which was used to change the probability of interaction between any two banks. If d_L was small, the possibility of any two banks exchange payments was limited to nearest neighbors. If d_L was infinite, the likelihood of any two banks exchanging payments was constant across the entire banking system.

The appendix provides more details as to how the simulation was written.

Results and Analysis:

The results of our simulation are reported in the tables shown below. Each table is laid out as follows: unless otherwise noted, σ^2, the variance of bilateral net debit and d, the payment default threshold were held constant. Each column corresponds to a specific value for N, the number of banks, while each row corresponds to a specific value for p, the probability of payment exchange between any two banks. Each element in the table is the percentage of banks that survive after the top debtor is removed and the subsequent unwinding. We report the mean percentage of surviving banks after 500 runs.

For example, according to the Table A in Table Set I, for 200 banks at an interaction probability of 0. 9, where loans to a defaulting bank are settled at 60% of the original value, on the average, 94 percent of the banks survive the shock of the system.

Table Set I shows data from the original model in GNKW. In Table A of Table Set I, the payment default threshold was set to 0.2 of the capitalization of bank while the variance of bilateral of net debit was set to 0.02. Loans from defaulting banks were called immediately and loans to defaulting banks were paid off at a reduced rate. Here it is 60% of the original value. (This is the value used throughout the study.)

In this simulation, we found that as the number of banks increased and as the interaction between banks increased, the percentage of banks that survived after the failure of a single bank decreased. This is shown in a more dramatic effect in Table B of Table Set I where the variance of bilateral net debit was increased to 0.04. As the completely unregulated banks increased interactions between each other, i.e., continue to mount possible debt between each other, the likelihood of systemic failure increased to the point that on the average with 300 banks interacting at a probability value of 0.9, only 5% of the banks would remain after the failure of the most debt ridden bank. Table C reinforces this result where the payment default threshold is decreased, thus making banks more sensitive to failure.

Table Set II demonstrates the remarkable impact of the diversification rule - the pooling of the banks funds and spreading loans over a wider spectrum of banks. The conditions for generating Table A in Table Set II were identical for Table B in Table Set I with the exception of the inclusion of the diversification rule. The result is the system increased its stability with an increase in the number of banks and probability of exchange. Indeed, in Table B of Table Set II, the variance of bilateral net debit was increased by an order of magnitude and yet the effect is still opposite to those seen in Table Set I.

Table C of Table Set II shows the mean value for the bilateral net debit of the top defaulting bank for the different values for the parameters p and N. As we increased the interaction between banks and the number of banks in the pool, the bank with the most debt was able to generate vastly excessive debt before being declared insolvent. And yet, as Table B shows, the system was virtually unaffected by the failure of this bank.

Table Set III shows data from the modifications done to add a dynamic element to the simulation. The parameters in Table A of this set were identical those in Table B of Table Set I except that the unwinding was triggered after a round where the bank with the largest multilateral net debit exceeded the payment default threshold. To within a standard deviation for each run of the simulation, the two tables are identical suggesting that the original model was sufficiently "dynamic." With the new triggering conditions, the simulation was run using the parameters found in Table B of Table Set II (the inclusion of the diversification rule). Table B of Table Set III reproduces Table B in Table Set II nearly to a number.

In Table C of Table Set III, we used the parameters from Table A except set the triggering mechanism to be when a bank's multilateral net debit exceeded the payment default threshold by a factor of 10. This allows a bank to achieve a tremendous debt before being declared insolvent. We found that with the exception of the conditions where N is small, Table C reproduced Table A which is identical to the "non-dynamic" model. The reason the percentage of banks failed in Table C was greater than in Table A for smaller N was because when banks were generating multilateral net debit of such size, they were doing it by creating loans of substantial size with only a few banks. Since there were fewer banks in the system, the few banks that did fail represented a larger percentage of the number of banks in the system.

The initial parameters of Table D of Table Set III were set to those in Table B of Table Set II, i.e., the diversification rule is applied to the system. The only difference was the use of the triggering system for bank closings which, like Table C of Table Set III, occurred when a bank has exceeded the payment default threshold by a factor of 10. Again except for systems where N is small, the results are identical. We found that the triggering occurs after 10-30 rounds of payments.

In Tables E, F and G for Table Set III, a third type of triggering system was used. Here the banks were allowed to exchange payments for 100 rounds before the top debtor was closed and the unwinding process was performed. We found that some banks were able to generate huge amounts of loans (see Table F) depending upon how frequently the banks exchanged payments. With no regulations, unchecked banks did produce scenarios where complete failure was observed (see Table E). We deemed the amount of possible net debt to be too excessive, hence unrealistic, and eliminated the dynamic model from the system.

In Table Set IV, we report the results of adding the local shock to the system. We used the dynamical system where the trigger for bank closure consisted of a bank exceeding the payment default threshold by several times its asset size. We did so because we wanted to test the system under the most extreme but realistic conditions.

To incorporate the local effects, we set the parameter p_L, the fraction of banks which experience a local shock to 0.10 in Tables A and B and to 0.20 in Tables C and D and provided the maximum shock by reducing loans values to bank closed in the area of sudden depressed financial status to 10% of their original value. In Tables A and C, the diversification rule was not applied. In Tables B and D, the diversification rule was applied. Again, when the diversification rule was applied, the variance of bilateral net debit was increased from 0.04 to 0.4.

We see that as we increased the size of the area which suddenly experiences depressed loan values, the affect on the other banks is more pronounced as fewer banks survived the unwinding process. However, the effects are small and do not change the overall properties of the system – particularly the one where the diversification rule was applied.

In Table Set V we see the effects of globalization which was part of the original model. Here we repeated the experiments reported in Tables C and D of Table Set III except we localized any possible interaction between banks. Specifically, the probability of interaction between banks was changed to be inversely proportional between the distance between the banks. For example, nearest neighbor banks such as banks i, i+1 and i-1 were more likely to exchange payments than banks i and i + N/2. (Note bank 1 and bank N are considered nearest neighbors.) The "distance" used to for the example runs shown in Tables A and B in Table Set V is 0.1, i.e., 10% of the total distance N.

We see when we compare Tables A and B which includes the localization effect with the equivalent tables C and D of Table Set III where exchange probability is independent of distance, the effect of localizing payment exchanges is significant both in the completely unregulated market and the system where the diversification rule is applied. This is because in the simulation, collections of banks were more likely to completely fail should one bank within that collection fail. Its few loans with the few other banks produced the famous "domino" effect, suggesting that systemic risk is likely in environments where free trade is highly restricted. Note though that some banks are able to "isolate" themselves in the unregulated market and hence reduce the likelihood of total systemic failure.

By increasing the distance a bank could exchange with another bank, we found the effects of the localization were reduced and the stable financial system we see in the original model based upon a global market was reproduced.

Summary

A crises in the financial market can be found in several situations: it may be as dramatic as a sudden devaluation of the currency, an unexpected drop in the real estate market, a sudden loss in trust in a stock market or the onset of massive inflation. The question remains how much regulation is required to guarantee the security of the financial system. Remarkably, the answer is to use the prudent man rule and diversify a banks expenses and assets. In this paper, we have modeled the effects of local and some global shocks on a closed financial system. While we find that a complete lack of regulation could lead to a system of significant systemic risk, the prudent men rule and a reasonable limit on interbank lending (in terms of p capitol) can practically eliminate this risk..

We examined 2 basic modifications to the original GNKW model. The first was to add a dynamic element to the payment exchange system. While we examined several possible models, we choose the most realistic but still potential dangerous model. We then used this modification to examine the effects of local shocks to the system. Not surprisingly, we found that as we increased the number of financial institutions affected by the sudden reduction in value of assets, the possibility of excessive financial disaster increased. However, the diversification rule continued to provide stability to the system.

Finally, we examined the effect of globalization by allowing the banks to either perform exchanges only locally or globally. The results were clear - by increasing the possible interactions between banks, the probability of local and global failure of the financial system decreased for the more realistic model with the diversification rule.

In conclusion, we reaffirm our view that a heavy regulatory burden on the banking sector is not necessary to assure bank stability. What are needed, it appears, are only the prudent man rule, good supervision, and adherence to extensive risk diversification to anchor the stability of the banking system.

Table Set I: GNKW Model:

Table A
Table entries: average percentage of banks remaining after the default of the largest net debtor and the subsequent unwinding of process. Payment default threshold = 0.2, variance of bilateral net debit = 0.02, loan sale rate = 60%.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	95
0.9	100	100	99	97	97	94	94

Table B
Payment default threshold=0.2, variance of bilateral net debit=0.04, loan sale rate=60%.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	99	99	99	99	99	99	98
0.5	99	96	85	67	53	33	15
0.9	98	80	54	40	31	12	5

Table C
Payment default threshold=0.1, variance of bilateral net debit=0.04, loan sale rate=60%.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	91	93	90	74	29	0.2	0
0.5	81	7	0.3	0	0	0	0
0.9	61	0.6	0	0	0	0	0

Table Set II: Original Model with Diversification rule

Table A
Table entries: average percentage of banks remaining after the default of the largest net debtor and the subsequent unwinding of process. Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. Diversification rule applied.

Probability of interaction	Number of banks: 5	25	50	75	100	200	300
0.1	95	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100

Table B
Payment default threshold=0.2, variance of bilateral net debit=0.4, loan sale rate = 60%. Diversification rule applied.

Probability of interaction	Number of banks: 5	25	50	75	100	200	300
0.1	75	92	97	99	99	100	100
0.5	78	99	99	100	100	100	100
0.9	85	99	100	100	100	100	100

Table C
Mean value for greatest net debtor's bilateral net debit across 500 runs. Payment default threshold = 0.2, variance of bilateral net debit = 0.4. Diversification rule applied.

Probability of interaction	Number of banks: 5	25	50	75	100	200	300
0.1	1.06	1.32	1.48	1.69	1.64	1.78	1.83
0.5	0.73	1.22	1.42	1.49	1.57	1.74	1.81
0.9	0.71	1.23	1.43	1.51	1.55	1.75	1.86

Table Set III: Effects of Dynamic modification

Table A

Table entries: average percentage of banks remaining after the default of the largest net debtor and the subsequent unwinding of process. Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. No diversification rule. Unwinding is triggered when at least one bank exceeds the payment default threshold.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	98	99	100	100	100	100	99
0.5	98	96	81	66	55	28	15
0.9	98	77	52	45	32	17	6

Table B

Payment default threshold = 0.2, variance of bilateral net debit = 0.4, loan sale rate = 60%. Diversification rule applied. Unwinding is triggered when at least one bank exceeds the payment default threshold. (Note variance is 10 times larger than in Table A.)

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	73	92	97	99	100	100	100
0.5	80	99	100	100	100	100	100
0.9	83	100	100	100	100	100	100

Table C

Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. No diversification rule. Unwinding is triggered when at least one bank exceeds 10 times the payment default threshold.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	70	85	87	89	86	94	98
0.5	48	29	57	64	55	29	17
0.9	25	29	53	43	31	12	5

Table D

Payment default threshold = 0.2, variance of bilateral net debit = 0.4, loan sale rate = 60%. Diversification rule applied. Unwinding is triggered when at least one bank exceeds 10 times the payment default threshold. (Note variance is 10 times larger than in Table C.)

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	72	85	91	99	97	100	100
0.5	51	58	97	99	100	100	100

0.9	29	68	98	100	100	100	100

Table E
Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. No diversification rule. Unwinding is triggered after 100 rounds of payments.

Probability of	Number of banks						
interaction	**5**	**25**	**50**	**75**	**100**	**200**	**300**
0.1	67	67	19	5	1	0	0
0.5	34	0	0	0	0	0	--
0.9	7	0	0	0	0	--	--

Table F
Mean value for greatest net debtor's multilateral net debit across 500 runs. Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. No diversification rule. Unwinding is triggered after 100 rounds of payments.

Probability of	Number of banks						
interaction	**5**	**25**	**50**	**75**	**100**	**200**	**300**
0.1	2.3	6.7	10.7	14.0	16.7	25.0	32.2
0.5	3.7	14.2	23.1	29.7	35.9	55.9	--
0.9	5.4	18.4	29.8	39.7	47.8	--	--

Table G
Payment default threshold = 0.2, variance of bilateral net debit = 0.4, loan sale rate = 60%. Diversification rule applied. Unwinding is triggered after 100 rounds of payments. (Note variance is 10 times larger than in Table A.)

Probability of	Number of banks						
interaction	**5**	**25**	**50**	**75**	**100**	**200**	**300**
0.1	64	61	16	4	1	0	0
0.5	31	0	0	0	0	0	--
0.9	6	0	0	0	0	--	--

Table Set IV: Effects of Local Shocks

Table A

Table entries: average percentage of banks remaining after the default of the largest net debtor and the subsequent unwinding of process. Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. No diversification rule. Unwinding is triggered when at least one bank exceeds 10 times the payment default threshold. A local shock affects 10% of the banks. The resale value of loans to these banks is 10% of the original value.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	67	83	85	85	81	88	83
0.5	43	24	53	56	50	25	14
0.9	20	27	49	39	27	13	8

Table B

Initial parameters identical to those found in Table A except that the variance of bilateral net debit = 0.4 and the diversification rule is applied. A local shock affects 10% of the banks. The resale value of loans to these banks is 10% of the original value.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	66	82	82	79	80	92	96
0.5	42	32	66	85	89	98	100
0.9	18	43	85	91	93	100	100

Table C

Initial parameters identical to Table A except local shock affects 20% of the banks. The resale value of loans to these banks is 10% of the original value.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	66	83	81	76	71	72	64
0.5	42	18	46	50	43	22	11
0.9	16	23	39	32	29	11	3

Table D

Initial parameters identical to Table B except that local shock affects 20% of the banks. The resale value of loans to these banks is 10% of the original value.

Probability of interaction	Number of banks						
	5	**25**	**50**	**75**	**100**	**200**	**300**
0.1	66	80	78	73	70	81	87
0.5	39	22	61	74	83	93	99
0.9	15	35	70	81	83	99	100

Table Set V: Effects of Local banking

Table A
Table entries: average percentage of banks remaining after the default of the largest net debtor and the subsequent unwinding of process. Payment default threshold = 0.2, variance of bilateral net debit = 0.04, loan sale rate = 60%. No diversification rule. Unwinding is triggered when at least one bank exceeds 10 times the payment default threshold. Banking is limited to nearest neighbors at +/- 10% of N banks.

Probability of			Number of banks				
interaction	**5**	**25**	**50**	**75**	**100**	**200**	**300**
0.1	60	42	47	62	55	31	19
0.5	62	38	43	64	55	30	21
0.9	61	34	48	65	55	33	21

Table B
Initial parameters identical to those found in Table A except that the variance of bilateral net debit = 0.4 and the diversification rule is applied. Banking is limited to nearest neighbors at +/- 10% of N banks.

Probability of			Number of banks				
interaction	**5**	**25**	**50**	**75**	**100**	**200**	**300**
0.1	59	19	13	35	57	98	100
0.5	61	41	61	89	99	100	100
0.9	62	52	72	94	99	100	100

Appendix: Technical description of simulation

Basic model:

The payment system of the banking industry is programmed by creating a N by N matrix, B, where entries of the matrix represent net payments from bank i to bank j - i is the column and j is the row. The simulation begins by assigning, at random, exchange interaction values (either yes or no) between pairs of banks. A binomial distribution with p, the exchange probability variable which is defined before the simulation begins, as the mean for the distribution is used to create the exchange interaction grid. Typical values for the probability of payment exchange are 10%, 50% and 90%. For each exchange, a random value based upon a normal or Gaussian distribution centered around zero is then assigned. This number represents the net payment between any two banks. Hence $B_{ij} = - B_{ji}$. The variance of the normal distribution for net payment, σ^2, is assigned before the simulation begins. Once the payment matrix is filled, the multilateral net debit for each bank is calculated:

$$F_i = \Sigma B_{ij}.$$

The initial value for each bank is stored as $F_i(0)$ so that it can be used for comparison with future multilateral net debit values.

The simulation begins by identifying the bank with the largest net debit. This bank is closed and is dropped from the simulation. The payments to and from this bank are then investigated. In the original MW model, all payments are eliminated, but in our previous work in this area, GNKW, we argued that loans to the defaulting bank should not be forgotten, but instead should be called.

In addition, loans that the defaulting bank owes on can be sold at a discounted rate. For this paper, our model is based upon the GNKW model - that there is a procedure in working with payments to and from a defaulting bank. Once this bank is eliminated and its loans are handled, the simulation recalculates the multilateral net debit for each bank, F_i, which changes given that some loans must be paid off immediately and that loans to a defaulted bank are now worth less than their original value. The difference between the new multilateral net debit and the original multilateral net debit is defined as the unexpected net debit. If the difference between the two values exceeds the predefined payment default threshold, d, the bank is considered to be in financial difficulty and is marked to be closed. The simulation continues by closing all marked banks and settling the payments between the marked banks and the standing banks. The simulation then recalculates the multilateral net debit for the remaining banks and determines if any are in financial difficulty. This process continues until either no banks remain or that the remaining banks possess unexpected net debit below the payment default threshold.

When the run is completed, the number of remaining banks and remaining payments are recorded. The simulation is run 500 times and a mean for the number of remaining banks and payments is reported.

Finally, our implementation of the diversification rule which eliminates systemic risk was performed by taking the variance of net debit, i.e., the possible size of a loan, and dividing it by both the probability of interaction and the number of banks.

Modifications to basic model:

The simulation was modified to add a dynamic element to the payment exchange process. The banks would be allowed to exchange payments until one of the conditions, chosen at the begin, were satisfied which would trigger bank closings. The three conditions investigated were:

1) the multilateral net debit, F_i for some bank was greater the default payment threshold, d.

2) Fi, was beyond several times d; or

3) a review of the banks were performed after some predefined number of rounds of payment exchanges.

As before, the interaction grid - the matrix which stored information as to whether two banks would exchange payments - was created first. Then using the random number generator with a normal distribution centered around zero and with a variance set by the parameter σ^2, payments between those banks which possessed payment interactions were generated. The multilateral net debit for each bank, F_i, was then calculated. If the predefined condition for bank closing was satisfied, the rounds of payment exchanges would stop and the simulation would execute the procedures as defined in the original model. If the predefined condition for bank closing was not satisfied, a new set of payments between banks would be added to the original set of payments. This would continue until either one of the conditions was satisfied or the number of rounds of payment exchanges exceed 10,000 at which point the simulation would stop and the run would be eliminated from the measurements.

The local shocks

As part of modeling the local shocks, the new parameters, p_L the percentage of banks within an area where a local shock occurs, r_{sL}, the rate at which loans to those banks within the area would be repaid and d_L, the distance factor, were assigned values. All local shocks occurred within banks between 1 and p_L * N. The effect of the shocks was model in the loans paid off by defaulting banks. When banks were closed in area where there was a local shock, r_{sL} instead of r_L, was used to calculate the value of the loans. In the model for the isolation of banks, we created a normal distribution function centered around zero where $1/ d_L^2$ was the variance. The difference between any two banks $d_{banks} = (i - j)$ was used as the distance between any two banks. Note we calculated this distance module N so that bank 1 and bank N were considered nearest neighbors. We then calculated the relative distance d_{banks} / N in the distribution function to find a multiplicative for the interaction probability parameter used to determine the likelihood that any two banks would exchange payments.

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